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Search for the tau-neutrino

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(Internal report)

Transparencies of a talk given at the P803 Collaboration meeting (1/14/90) at Fermilab, (and also in a Nevis Seminar on 1/31/90) proposing the idea to use the P803 hybrid emulsion spectrometer with 1 ton of emulsion in a proton beam dump for the detection of the tau-neutrino. Previous proposals for the tau-neutrino are reviewed. In particular the Fermilab proposal P646 (Baltay et al) is examined in detail and the method of calculation of the number of expected tau-neutrinos is applied in the case of P803 for 1 ton of emulsion, at various distances from the dump. The Ds/D ratio is assumed to be 0.3 and the branching ratio of Ds to tau+neutrino (Ds => tau + tau-neutrino) is assumed to be 0.03. The final selection of tau-neutrinos is based on impact parameter cut of 25 microns. The number of detectable tau-neutrinos in all decay modes of the tau lepton at distance 50 m for 2 x 10**18 protons is 592, out of which 400 correspond to only hadronic modes. The tau-neutrino yield is given for various distances and number of protons.

ν_τ Search

G. Tzanakos
1/14/90

- τ does not couple to ν_μ, ν_e
(Neutrino experiments)

- Number of neutrinos $N_\nu = 3$
(LEP)

Q. What is the ν_τ, τ coupling

$$\begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$$

Indirect evidence: V−A (e^+e^-)
τ decay, $\rho = 0.74 \pm 0.05$

But
need to be directly observed

$$\nu_\tau + N \longrightarrow \tau^- + X$$

τ decay modes

$$\tau^- \longrightarrow \nu_\tau + e^- + \bar{\nu}_e \qquad 18\%$$

$$\longrightarrow \nu_\tau + \mu^- + \bar{\nu}_\mu \qquad 18\%$$

$$\longrightarrow \nu_\tau + \pi^- \qquad 10\%$$

$$\longrightarrow \nu_\tau + \rho^- \qquad 21\%$$

$$\longrightarrow \nu_\tau + A_1^- \qquad 10\%$$

$$\longrightarrow \nu_\tau + N\pi \qquad 23\%$$

$$\tau_\tau \simeq 3 \times 10^{-13} \text{ sec}$$

Beam Dump Experiment

$p + \text{Dump} \rightarrow D_s + \cdots$

$D_s \rightarrow \tau \, \nu_\tau$

$\quad\quad \lfloor\!\!\longrightarrow \nu_\tau + \cdots$

Background: Prompt neutrinos

$\nu_\mu, \bar{\nu}_\mu, \nu_e, \bar{\nu}_e$ from charm decays

$D \rightarrow K \mu \nu_\mu$

$\;\;\; \rightarrow K e \nu_e$

Also from π, K decays

(greatly suppressed.)

Previous Attempts

R. Fine et al (Lee) 1979

Tag ν_τ with μ from decay $\tau \to \mu \nu \nu_\tau$

400 GeV machine

500 ton detector (Scintil + Drift Ch.)

Exploit kinematical differences between ν_τ, ν_μ.

After cuts:

$$\left.\begin{array}{l} 540\ \nu_\tau\ ,\quad 730\ \nu_\mu \\ 200\ \bar{\nu}_\tau\ ,\quad 300\ \bar{\nu}_\mu \end{array}\right\} \Rightarrow \frac{S}{N} = 1$$

x, y distributions different.

2. E.S. Hafen et al. (Pless) 1980
Fermilab P636

High resolution bubble chamber
as vertex detector
+
Multiparticle spectrometer.

B.C. 36" dia, 24" long
Freon ($\rho = 1.5\ g/cm^3$)

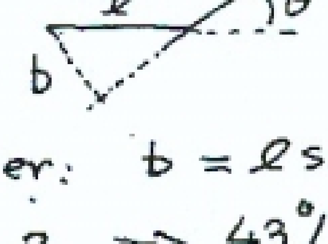
$\Rightarrow$ <u>0.6 tons</u>

$L = 50\,m$ from bump.

For 2.5×10^{18} POT (1 TeV)

1467 τ^-
733 τ^+

2,200 τ's



Impact parameter: $b = \ell \sin\theta$

Require $\frac{b}{\delta b} > 2 \Rightarrow$ <u>43%</u> $\Rightarrow$ <u>946</u> events survive

3. H. H. Bingham et al (Baltay) 198[illegible]
Fermilab P646

Fermilab 15 ft Bubble chamber
Improved optics

B.C. 6′ dia × 9′
H - Neon ($\rho = 0.75 g/cm^3$)

⟹ <u>21.6 tons</u>

L = 250 m from dump
For 2×10^{18} POT (1 TeV)
⟹ <u>1200</u> events

Impact parameter and length
cuts ⟹ <u>75</u> events

LAYOUT OF THE MUON SHIELD

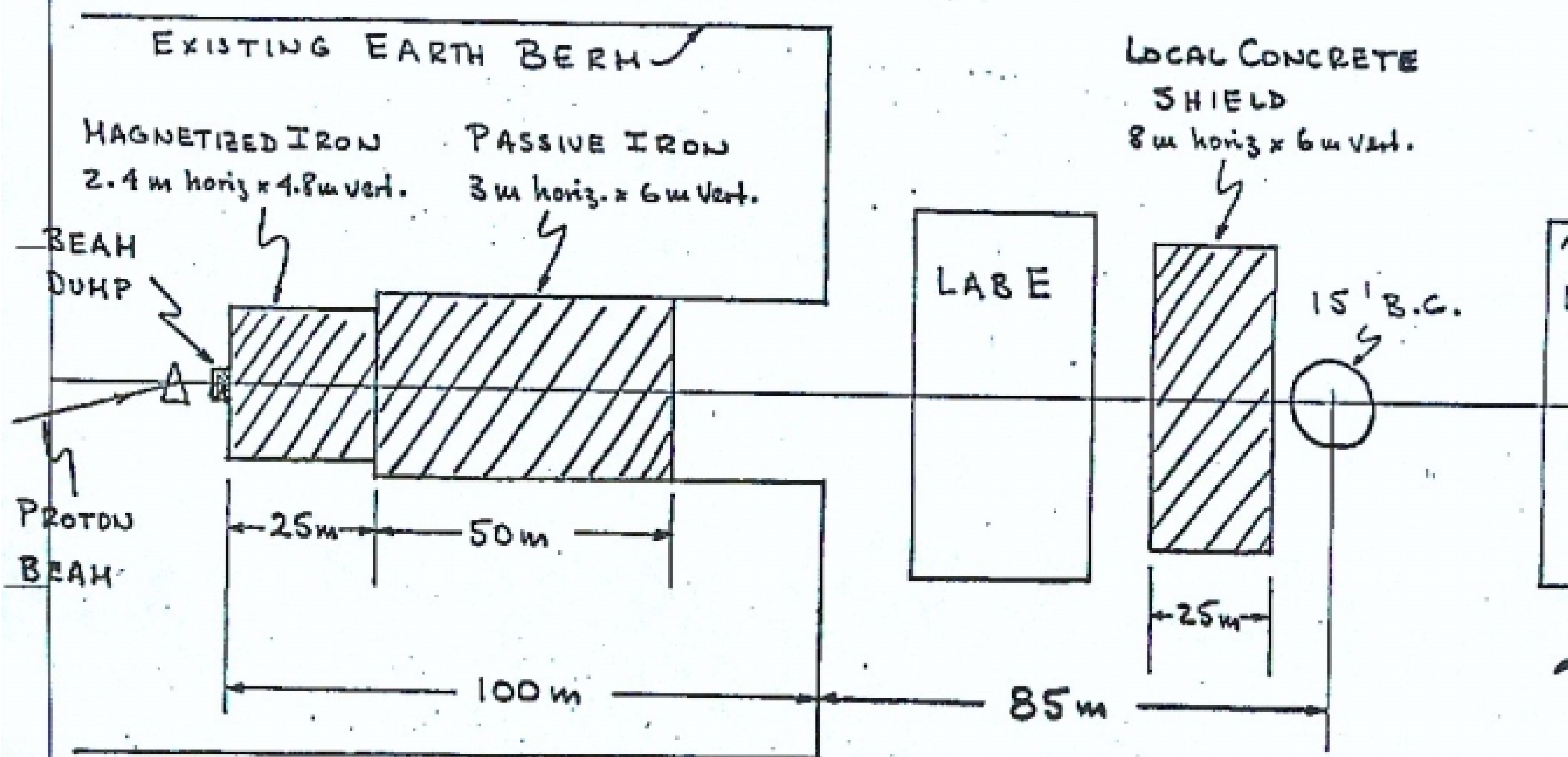


Fig 1

GENERAL LAYOUT OF THE BEAM DUMP NEUTRINO BEAM

IN THE NEUTRINO AREA

(Not to Scale)

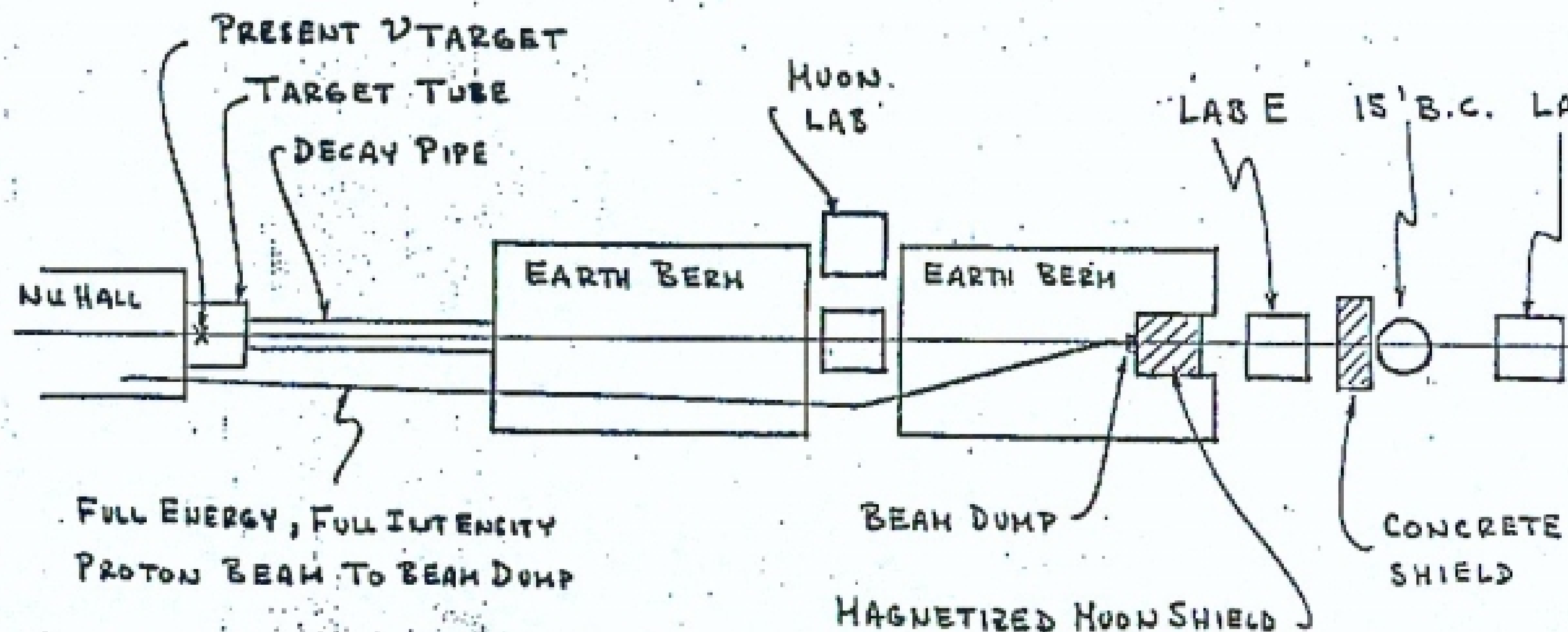


Fig. 1a

P646 (Baltay)

Calculation of fluxes and event rates

Extrapolate from BEBC (1977, 1979)

1.15×10^{18} POT, 400 GeV

L = 820 m from beam dump

E > 10 GeV

Event type	Total	From π,K decay	From prompt ν
CC ($\nu_\mu, \bar{\nu}_\mu, \nu_e, \bar{\nu}_e$)	148	87	61
NC	33	16	17

Scale for the Tevatron:

$$N_{cc}(\text{prompt } cc) \simeq 61 \times R(\text{proton}) \times$$
$$\times R(\text{D production})$$
$$\times R(\Omega) \times R(\sigma)$$

where:

$R(\text{proton})$ = proton ratio

$R(\text{D production})$ = increase in inclussive D production from 400 GeV to 1 TeV

$R(\Omega)$ = increase in the solid angle subtended by the detector

$R(\sigma\nu)$ = increase in event rate due to cross section increase at higher energies

$L_{15'} \simeq 200\,m$

$M_{15'} \simeq M_{BEBC}$

Roughly :

R(D production) $\sim$ E ratio

R(Ω) $\sim$ $\frac{E^2}{L^2}$ ratio

R(σν) $\sim$ E ratio

R(D prod.) = 2.1

(Bourquin-Gaillard model)

$$R(\Omega) = \left(\frac{1000}{400}\right)^2 \times \left(\frac{820}{200}\right)^2 = 6.25 \times 16.8 = 105$$

(42 by MC)

$$R(\sigma\nu) = \frac{1000}{400} = 2.5$$

(1.2 by MC)

More carefull estimate of
$R(\Omega)$, $R(GV)$: Monte Carlo

- Generate D, D_s in Dump

$D \rightarrow K\mu\nu$
$\rightarrow Ke\nu$

$D_s \rightarrow \tau + \nu_\tau$
$\quad \hookrightarrow \nu_\tau + \cdots$

- Propagate ν's to the detector

- check sensitivity on details of charm production:
3 different models

insensitive {
a) Bourquin - Gaillard
b) D's have same x_F, P_T as π's, K's
c) Best fit to charm production with $(1-x_F)^3 e^{-2P_T}$
}

$R(\Omega) = 3.8 \times 11 = 42$

↑ Energy (under 3.8) — ↑ Dump-detector distance (under 11)

$R(GV) = 1.2$

ν_τ flux

$$\frac{\nu_\tau}{\text{prompt } \nu} = \frac{(D_s \text{ production})}{(D \text{ production})} \times \frac{2 \times BR(D_s \to \tau + \nu_\tau)}{BR(D \to e + X) + BR(D \to \mu + X)}$$

$$BR(D_s \to \tau + \nu_\tau) \simeq 0.03$$

$\frac{D_s}{D}$ is like $\frac{K}{\pi} \simeq 0.1 - 0.15$

~~[illegible]~~ but $\frac{D_s}{D} > \frac{K}{\pi}$

take $\frac{D_s}{D} \simeq 0.3$

$\Rightarrow$

$$\frac{\nu_\tau}{\text{prompt } \nu} \simeq 0.3 \, \frac{2 \times 0.03}{0.08 + 0.08} \simeq 0.11$$

$\Rightarrow$

$$N(\nu_\tau + \bar{\nu}_\tau) \simeq 0.11 \times 11{,}000 = \boxed{1200} \text{ events}$$

For 2×10^{18} POT, 1 TeV, at 200m

N_{cc}(prompt CC) $\simeq$ 11,000 CC

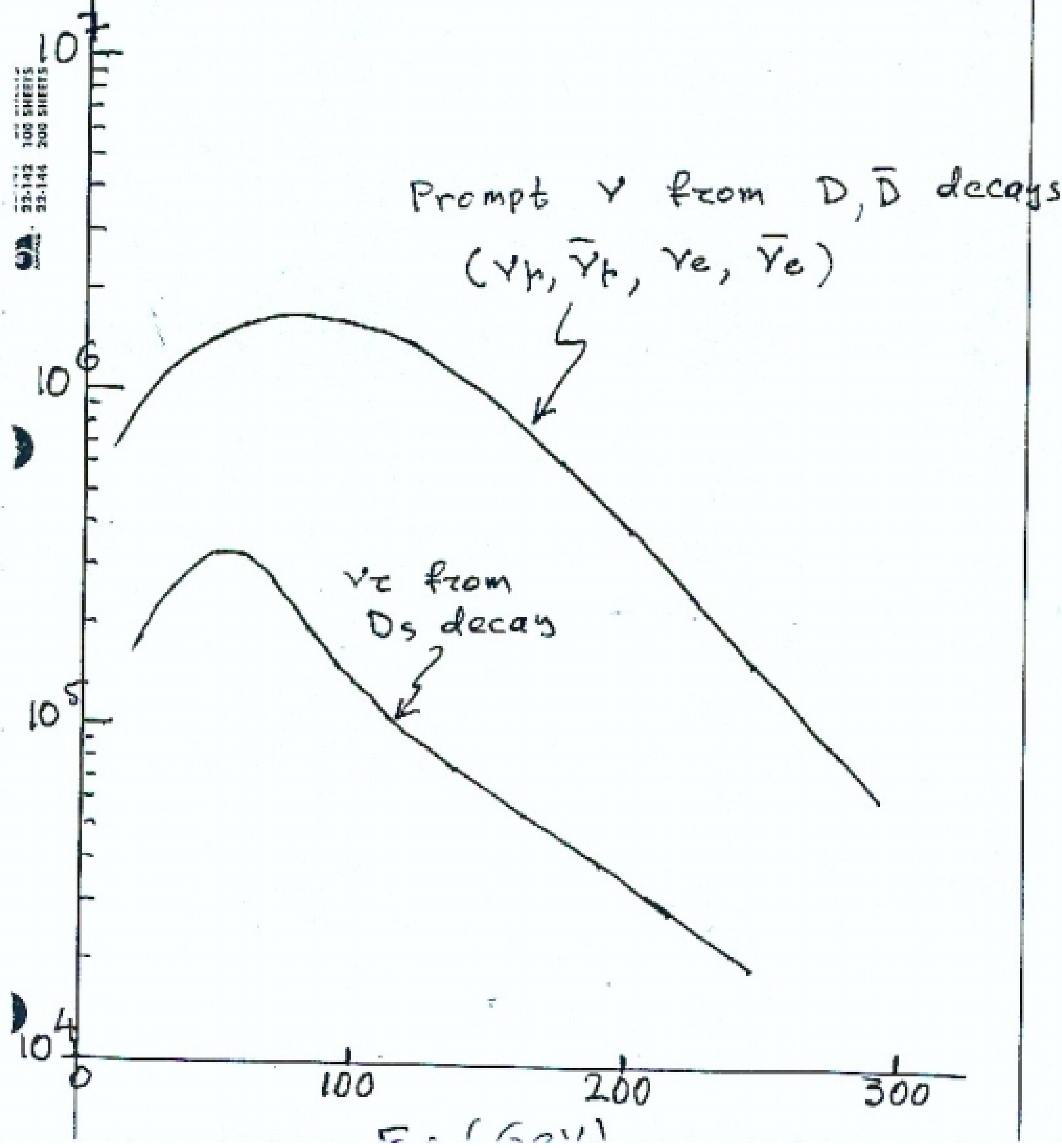
$$\left(\simeq 61 \times \frac{2\times10^{18}}{1.15\times10^{18}} \times 2.1 \times 42 \times 1.2 \right)$$

Breakdown:

Event type	Prompt	From π, K decays	Total
$\nu_\mu + Ne \to \mu^- + \cdots$	4,000	2,000	6,000
$\bar{\nu}_\mu + Ne \to \mu^+ + \cdots$	1,600	800	2,400
$\nu_e + Ne \to e^- + \cdots$	4,000		4,000
$\bar{\nu}_e + Ne \to e^+ + \cdots$	1,600		1,600
(prompt CC subtotal)	11,200		
NC	3,900	900	4,800
$\nu_\tau + Ne \to \tau^- + \cdots$	850		850
$\bar{\nu}_\tau + Ne \to \tau^+ + \cdots$	350		350
(τ subtotal)			1200

Beam Dump ν fluxes

1 TeV , L = 200 m



Detection efficiency

Efficiency for observing in-flight τ-decays

M-C, ν_τ spectrum from $D_s \to \tau \nu_\tau$
$\hookrightarrow \nu_\tau + \cdot$

$\nu_\tau, \bar{\nu}_\tau$ interactions in Neon
θ, P

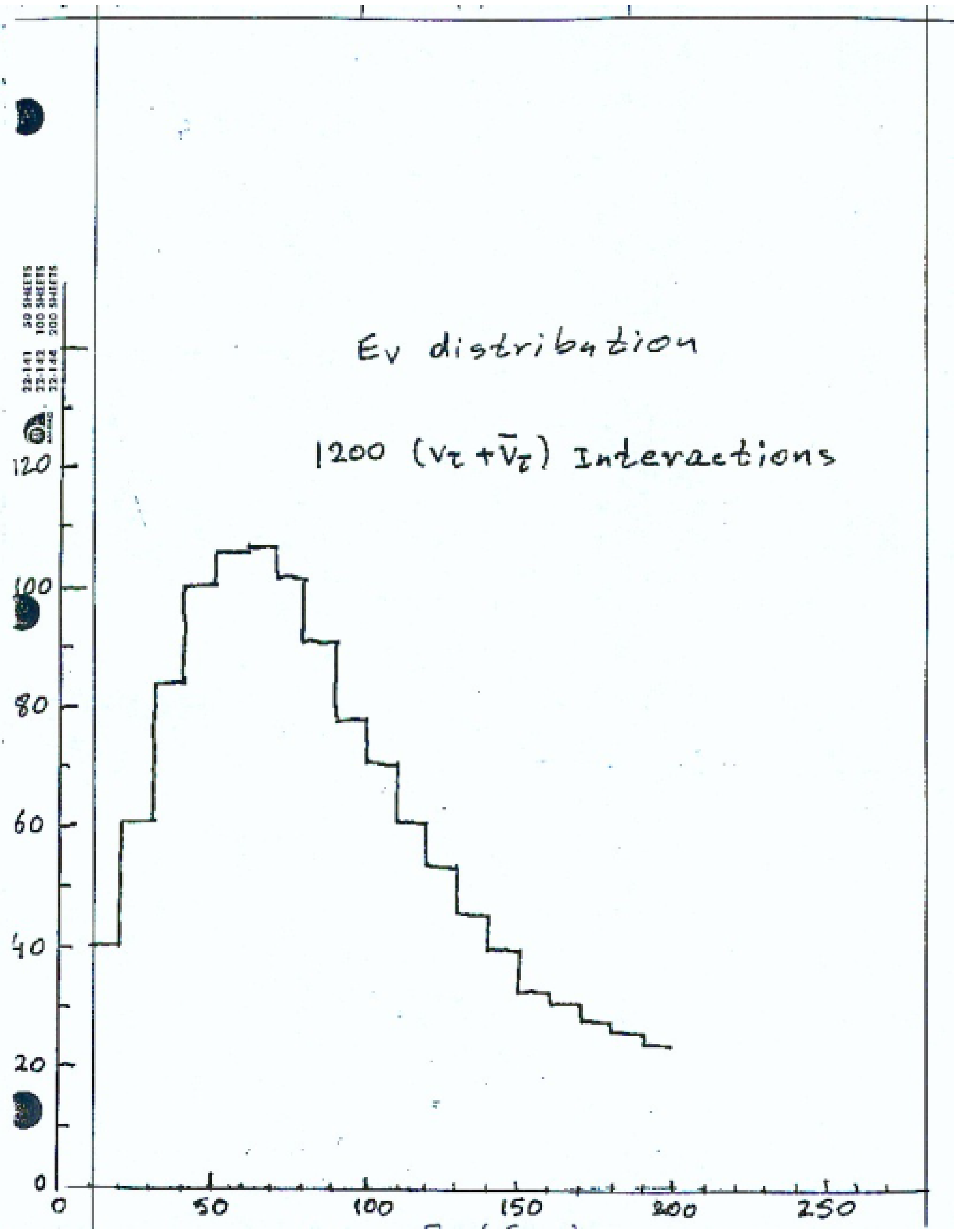
- E_ν distribution for 1200 events
- P_T distribution
- Decay length distribution
- Fraction of decays beyond distance l from vertex

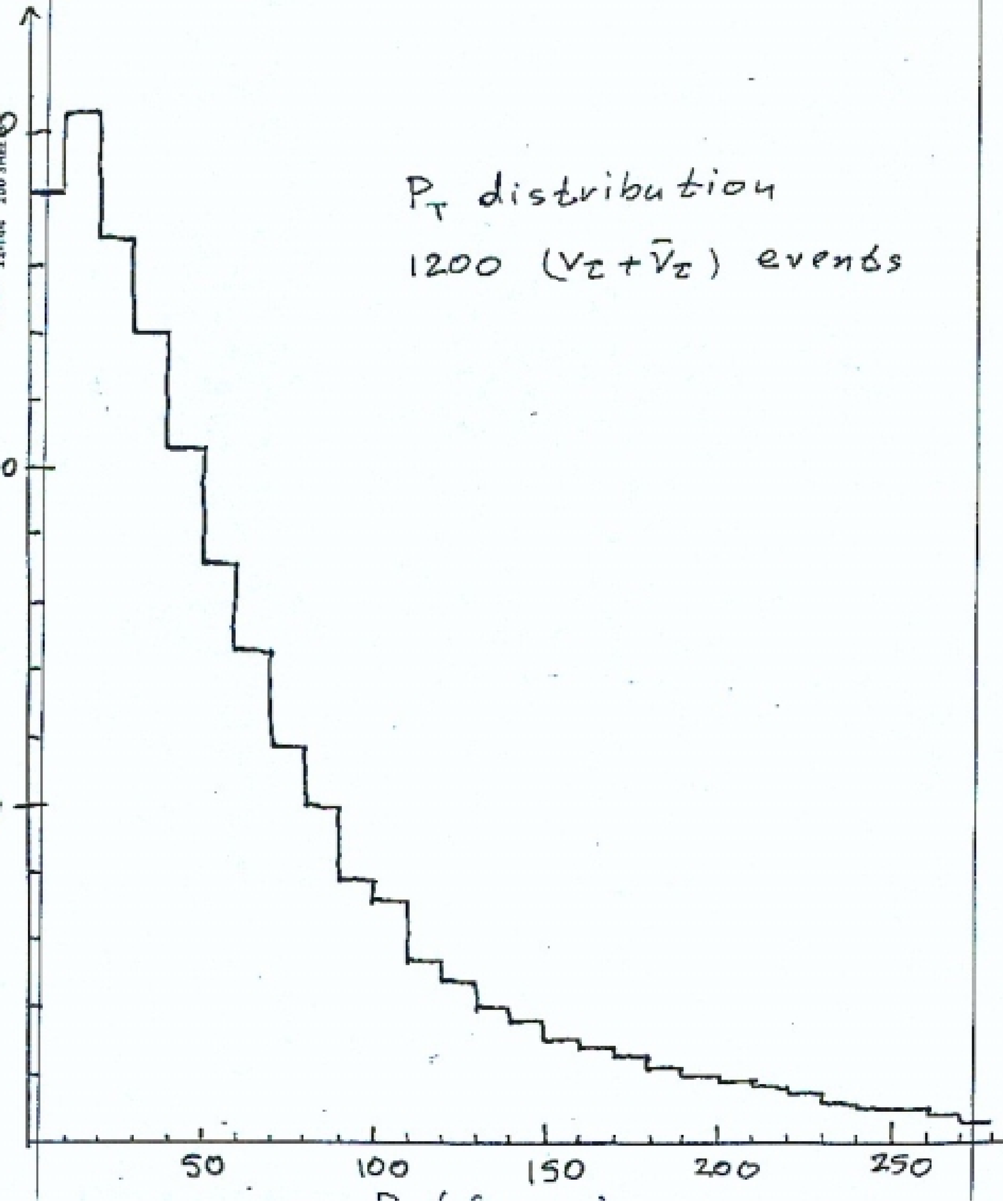
19% of decays (230 events) $l \geq 0.5$ c

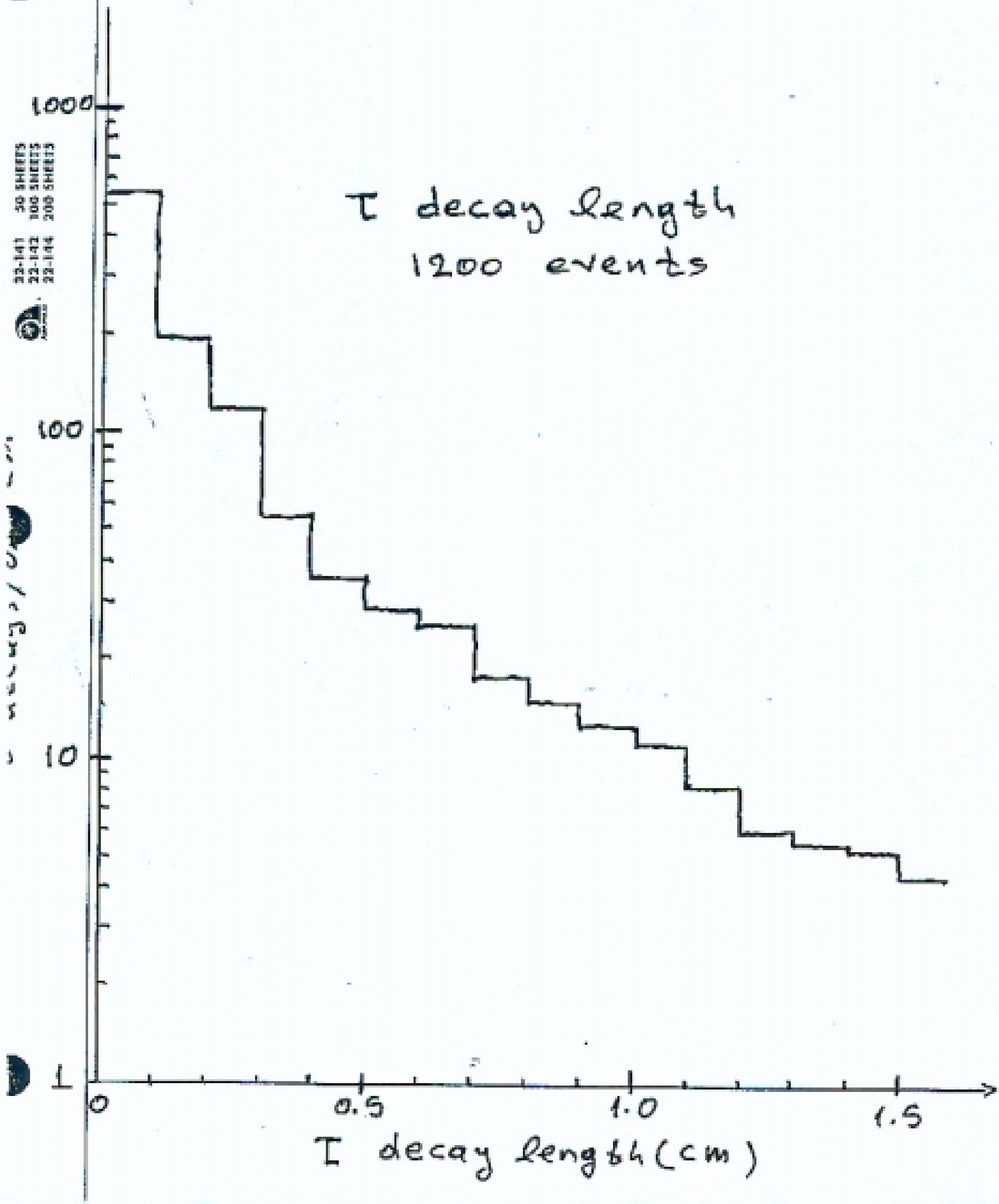
(80% $\Rightarrow$ 960 events at $l \gtrsim 30\mu m$)

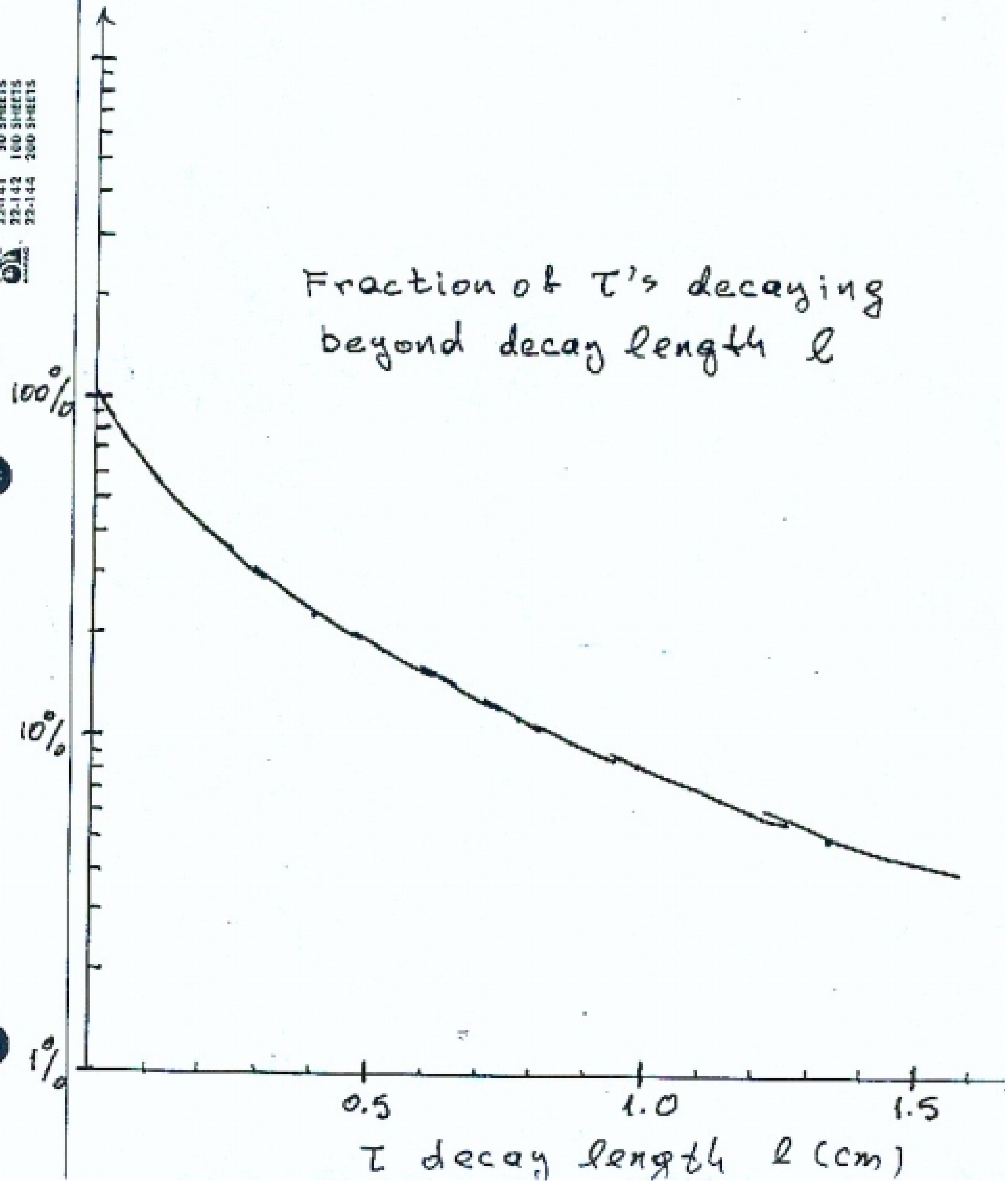
Watch out! Small decay angles in lab

Efficiency different for various τ-decay modes


Eν distribution
1200 (ντ + ν̄τ) Interactions
0
20
40
60
80
100
120
0
50
100
150
200
250


150
100
50
P_T distribution
1200 $(\nu_\tau + \bar{\nu}_\tau)$ events
50
100
150
200
250


τ decay length
1200 events
1000
100
10
1
0
0.5
1.0
1.5
τ decay length (cm)


Fraction of τ's decaying
beyond decay length ℓ
100%
10%
1%
0.5
1.0
1.5
τ decay length ℓ (cm)

Efficiencies of τ-decay modes

i) $\tau \longrightarrow \ell\, \nu_\ell\, \nu_\tau$ 18% e

18% μ

Kinematics

$$P_{\parallel} = \gamma P_{cm} (1 + \cos\theta^*)$$

$$P_T = P_{cm} \sin\theta^*$$

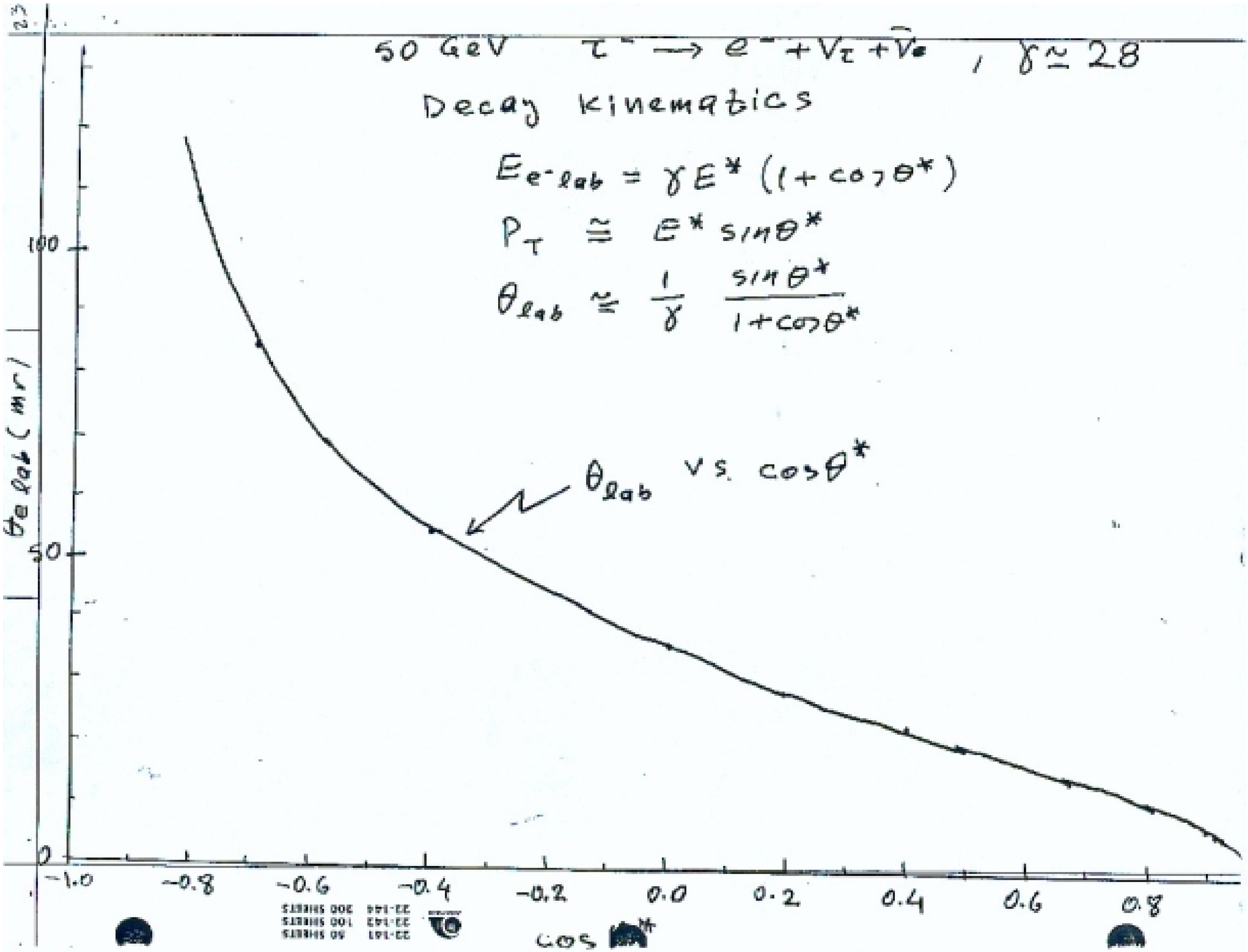
$$\theta_{Lab} \simeq \frac{P_T}{P_{\parallel}} = \frac{\sin\theta^*}{\gamma(1+\cos\theta^*)}$$

θ_{lab} vs. $\cos\theta^*$

in 15' B.C. $\theta_{lab} > 5°$ is detectable

(In emulsion $\theta_{lab} > ?$)

θ_{lab} (mr)	%
87	15
70	21
50	35
40	45
30	60
10	93



50 GeV $\tau^- \rightarrow e^- + \nu_\tau + \bar{\nu}_e$, $\gamma \simeq 28$
Decay kinematics
$E_{e^- lab} = \gamma E^* (1 + \cos\theta^*)$
$P_T \cong E^* \sin\theta^*$
$\theta_{lab} \cong \frac{1}{\gamma} \frac{\sin\theta^*}{1+\cos\theta^*}$
θ_{lab} vs. $\cos\theta^*$
$\theta_{e\,lab}$ (mr)
0
50
100
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
$\cos\theta^*$

in B.C. (15')

$\varepsilon = 0.18 \times 0.15 \simeq 3\%$ of τ's

in Emulsion

$\varepsilon = 0.18 \times 0.93 \simeq 17\%$ of τ's

Better parameter:

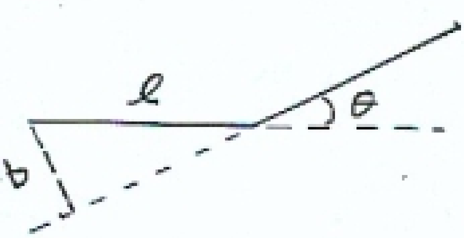
Impact parameter b

Decay length $\sim \gamma$

decay angle $\sim \frac{1}{\gamma}$

$b =$ (Decay length) $\times$ (decay angle)

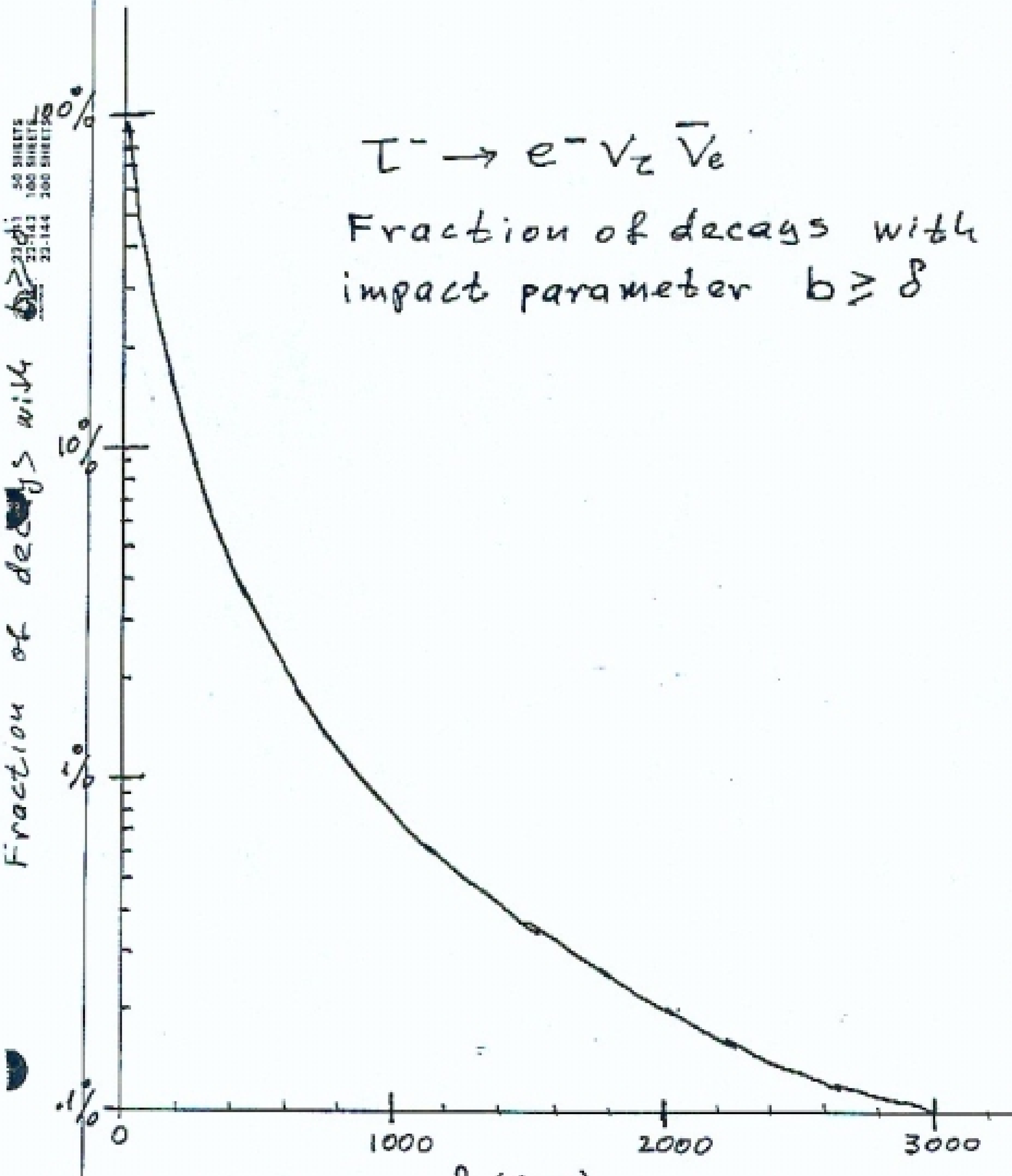
indep. of γ



$\ell = \beta \gamma c \tau_0$

$$b \simeq \beta \gamma c \tau_0 \frac{1}{\gamma} \frac{\sin\theta^*}{1+\cos\theta^*} \simeq \beta c \tau_0 \frac{\sin\theta^*}{1+\cos\theta^*}$$

— b distribution



$\tau^- \to e^- \nu_\tau \bar{\nu}_e$
Fraction of decays with impact parameter $b \geq \delta$
Fraction of decays with $b \geq \delta$
100%
10%
1%
.1%
0
1000
2000
3000
δ (μm)

Visible τ (τ^+, τ^-) decays

2×10^{18} POT, 21.6 ton, L = 200m

Decay Mode	BR	Events Expected	ϵ_{vis}	N_{vis}
$\tau \to e \nu_\tau \nu$	.18	215	2.5%	5
$\tau \to \mu \nu_\tau \nu$	.18	215	2.5%	5
$\tau \to 1h^c \nu_\tau$ (neu)	.33	400	2.5%	10
$\tau \to 3h^c \nu_\tau$ (neut)	.31	370	15%	55
		1200		75

– Fraction of events with $b \geq \delta$

δ (μm)	%
500	3
200	13
100	27
50	46
25	60

what is δ for emulsion?

Assume $\delta = 25\,\mu m$!

(ii) $\tau \to 1h^{\pm} + \nu_\tau + \text{neutral}$

Like e, μ's

(iii) $\tau \to 3h^{\pm} + \nu_\tau + \cdots$

Easier, depends on ℓ

for 15' B.C. $\epsilon(\ell \geq 0.5\,cm) \simeq 15\%$

(For emulsion $\varepsilon(\ell \geq 30\,\mu m) \simeq 80\%$)

P 803

Visible τ (τ^+, τ^-) decays

Assume:

2×10^{18} POT, 21.6 ton, $L = 200$ m

Decay	BR	Expected	ϵ_{vis}	N_{vis}
$\tau \to e \nu \nu_\tau$	.18	215	.6	129
$\tau \to \mu \nu \nu_\tau$	.18	215	.6	129
$\tau \to 1h + \cdots$	.33	400	.6	240
$\tau \to 3h + \cdots$	.31	370	.8	296
		1200		794

All decay modes $\Longrightarrow$ 794

Hadronic $\Longrightarrow$ 536

Visible ν_τ's, $M = 1$ ton emulsion

$b_{min} = 25\ \mu m$, all decay modes

N_p \ L (m)	50	75	100	125	150	175	200
2×10^{18}	592	263	148	95	66	48	37
3×10^{18}	888	395	222	143	99	72	56
4×10^{18}	1184	526	296	190	132	96	74
5×10^{18}	1480	658	370	238	165	120	93
6×10^{18}	1776	789	444	285	198	144	111

Only hadronic modes

N_p \ L (m)	50	75	100	125	150	175	200
2×10^{18}	400	178	100	64	44	33	25
3×10^{18}	600	267	150	96	66	50	38
4×10^{18}	800	356	200	128	88	66	50
5×10^{18}	1000	445	250	160	110	83	63
6×10^{18}	1200	534	300	192	132	99	75

1/14/90
Meeting

P 803 AGENDA

REAY: PEOPLE, POLITICS

TZANAKOS: ν_τ DUMP EXPT

KOIZUMI: CONSTRUCTION

NIWA: EMULSION WORK, FIBERS, ELASTIC SCATT. TEST

ROSENFELD: TRIGGERING, CHAMBE

NEXT MEETING: SATURDAY FEB 10 9 AM FERMILAB ?

ALSO INCLUDED
a) TZANAKOS' CALORIMETER TRANSPARENCIES FROM DECEMBER MEETING
b) SIDWELL'S MONTE CARLO ON HIT DENSITIES IN CALORIMETER. (WOULD HAVE BEEN PRESENTED IF SIDWELL WERE NOT SICK)